FISHERY RESEARCH

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Project 7. Irrigation Diversion Fish Loss Reduction

Subproject 1. Teton River Irrigation Canal Investigations
Subproject 2. Inventory of Physical Characteristics of Canals in Magic Valley, Southeast, and Upper Snake Regions
Subproject 3. Synopsis of Information on Behavioral Barrier and Guidance Systems

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ANNUAL PERFORMANCE REPORT

State of: Idaho

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Title: Irrigation Diversion Fish Loss Reduction

Subproject No.: 1. Teton River Irrigation Canal Investigations

Contract Period: April 1. 1995 to March 31. 1996

ABSTRACT

Field operations in 1995 focused on developing sampling methods for estimating losses of resident salmonids to irrigation diversions. Hoop traps, screw traps, and fyke nets were evaluated in irrigation diversions on the lower Teton River during July and August. Overall catch rates were low. The small catches could have been a function of seasonal or behavioral influences, low instream fish densities, or other factors. Continuously fluctuating canal flows and the use of herbicides complicated trap efficiency estimates.

Past research on the Lemhi River suggested trapping fish at screen bypasses is the only means of determining the actual movement of fish down irrigation diversions. Rather than directly trapping fish in canals, the proportion lost to diversions could be more efficiently estimated by releasing marked fish upstream of screened canals and recapturing them in screen bypass traps.

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INTRODUCTION

Idaho fishery managers and anglers have long suspected that significant numbers of resident game fish are lost to irrigation diversions. However, there is little quantitative data available to assess the effects of such losses on stream populations, or to even determine whether a widespread problem exists.

The conditions for potentially harmful repercussions are certainly present. Hundreds of streams are diverted for agricultural purposes statewide, with irrigation diversions ranging in size from a few cfs to 4,500 cfs. Although the majority of diversions in the Salmon River drainage and a few diversions in southeastern Idaho are screened to protect against fish loss, most irrigation diversions in the state are not.

The goal of this research project islo determine under what circumstances and to what degree sport fishing opportunities could be enhanced by minimizing losses of resident salmonids to irrigation diversions. The biological significance of these losses will be evaluated by estimating the proportion lost and modeling the effect of this source of "exploitation" on stream populations. If losses are shown to have a significant impact on Idaho fisheries, then diversion systems that adversely affect resident stocks will be identified based on canal characteristics known to influence fish loss (Spindler 1955). The cost-benefit for loss management will be evaluated and promising technologies for loss prevention will be recommended.

This was the first year of a study that will evaluate the impact of irrigation diversions on resident salmonids. Field operations during 1995 focused on evaluating sampling methods for estimating losses of resident salmonids to irrigation diversions. This report evaluates the effectiveness and limitations of various gear types for trapping fish in canals.

RESEARCH GOAL

The goal of this research project is to determine under what circumstances and to what degree sport fishing opportunities could be enhanced by minimizing losses of resident salmonids to irrigation diversions.

OBJECTIVES

1. To assess the population effects of resident salmonid losses to irrigation diversions.
2. To identify diversion systems that adversely affect resident salmonid stocks.
3. To evaluate the cost-benefit of loss management.
4. To recommend promising loss prevention technologies.

Task

To evaluate trapping techniques in irrigation diversions on the lower Teton River and recommend techniques for future sampling operations.

METHODS

There are 17 decreed main and lateral canals ranging in size from 16 cfs to 609 cfs on the Teton River downstream of the Teton Dam site. Canal company presidents were contacted for access permission and four of the main canals were selected for trap evaluations: the Wilford (286 cfs) and Teton Irrigation (128 cfs) canals, located on the mainstem Teton River downstream of the dam site, and the Woodmansee-Johnson (60 cfs) and Rexburg City (54 cfs) canals on the South Fork Teton River. All but the Woodmansee-Johnson Canal are situated on river bends and all are associated with concrete or boulder diversion dams.

Two types of hoop traps were fished simultaneously in the Wilford, Woodmansee-Johnson, and Rexburg City canals weekdays from July 17 to August 25. These canals were characterized by relatively slow water velocities (less than 0.3 m/s), which made them appropriate sites for hoop traps. The hoop traps were constructed from 0.9 m diameter steel rings covered with 6.25 mm mesh Delta knotless netting. The first type of hoop trap measured 0.9 m in diameter x 1.8 m long and had one crowfoot throat necked-down with a drawstring to a 10 cm opening. The second type measured 0.9 m in diameter x 2.4 m long and had two crowfoot throats, with the opening on the leading throat also drawn-down to a 10 cm opening. The traps were spread with appropriate lengths of conduit, weighted with rail iron attached by a carabiner to the leading hoop, baited with commercial marshmallow trout bait or cheese, and placed 25 m to 100 m downstream of canal headgates. The traps were fished side-by-side to minimize bias introduced by bank preference. Weekly catch rates for each trap type were compared with a paired-T test (Zar 1984) to evaluate relative effectiveness.

A screw trap was fished in the Teton Irrigation Canal weekdays from July 19 to August 10, and a wingless fyke net from August 21 to 25. Water velocities in excess of 4 m/s facilitated proper operation of these two trap devices. The screw trap measured 4.9 m long x 2.8 m wide and was equipped with a 1.5 m diameter cone. The fyke net was constructed from 6.25 mm mesh Delta knotless netting, had a 1.2 m x 1.2 m entrance that tapered down to a 12.5 cm D-zippered collar at the codend, and measured 3.6 m long. A floating trap box was connected to the fyke net collar via a 10 cm diameter flex hose. The traps were installed about 50 m downstream of the canal headgate.

All fish were counted and given an upper caudal fin clip to prevent repeat sampling. All trout were measured to the nearest mm for total length (TL), weighed to the nearest 0.1 gram, and sampled for scales. Trap efficiency was evaluated by releasing uniquely marked groups upstream of the trap site when sufficient samples were collected. Staff gauges were installed at the trap sites and stage heights were recorded daily. Effort in hours was recorded for each trap.

RESULTS

The total catches of salmonids (cutthroat trout *Oncorhynchus clarki,* rainbow trout O. *mykiss,* and mountain whitefish *Prosopium williamsoni)* and forage fish (dace *Rhinichthys spp.,* redside shiner *Richardsonius balteatus,* and sucker *Catostomus spp.)* were 38 and 821, respectively (Table 1). The fyke net yielded the highest overall catch rate, but this only reflects one week of trapping and a large catch of forage fish. The screw trap yielded the second highest overall catch rate, and the highest rate for salmonids. Forage fish were consistently caught at higher rates than salmonids by all trap types.

The catch rate for salmonids was lowest in the Woodmansee-Johnson Canal, and lowest for forage fish in the Rexburg City Canal (Table 2). Possible herbicide-related trap mortalities were observed in the Rexburg City and Woodmansee-Johnson canals on July 26-27 and August 1, respectively, suggesting herbicide applications may have reduced catchable populations in these canals. Catch rates for salmonids (Figure 1) and forage fish (Figure 2) did not appear to be related to staff gauge heights.

The difference between catch rates for one-throated and two-throated hoop traps was not significantly different from zero ($P>0.05$) (Appendix A). However, this may not be meaningful since the minimum detectable difference between mean catch rates for each gear type (0.32) was larger than the mean difference ($|x_D|$ = 0.15). Further, the overall catch rate for two-throated hoop traps was twice as high as for the one-throated version (Table 1).

Insufficient catches precluded trap efficiency evaluations. One group of about 40 forage fish were marked and released upstream of the trap site in the Woodmansee-Johnson Canal, but none were recaptured.

Small fish predominated the catch. About 97% of the trout and 96% of the forage fish captured were less than 100 mm TL. The mean length of cutthroat trout was 57 mm TL versus 40 mm TL for rainbow trout (Table 3). All cutthroat and rainbow trout were young-of-the-year fish, except for one yearling cutthroat (212 mm TL).

DISCUSSION

All but the Woodmansee-Johnson canal were situated on the outside of river bends and all were associated with concrete or boulder diversion dams. Although other factors may come into play, Spindler (1955) found fish losses were highest in canals with these features (see Subproject 2). However, overall catch rates were extremely low for both salmonids and forage fish.

The small catches could have been a function of seasonal or behavioral influences, low instream fish densities, or other factors. For example, studies on the Gallatin River, Montana have shown most fish enter canals during peak river flows, while little movement into canals occurs during the summer and fall (Clothier 1953; Eric Reiland, Montana State University, personal communication). Consequently, fish that entered and moved down the study canals during the spring runoff may not have been vulnerable to capture. The absence of large trout in the overall catch may be attributed to trap avoidance or some other behavioral factor.

Table 1. Catch and catch-per-unit effort (CPUE) by gear type and fish group, Teton River canals, 1995.

Gear[a]	Forage Fish[b]	Salmonids[c]	Total
		Catch	
HT1	219	4	223
HT2	430	5	435
ST	104	28	132
FN	68	1	69
Total	821	38[d]	859
		CPUE fish/hour	
HT1	0.138	0.003	0.140
HT2	0.289	0.003	0.292
ST	0.332	0.089	0.421
FN	0.788	0.012	0.777

[a]HT1=one-throated hoop net, HT2=two-throated hoop net, ST=screw trap, FN=fyke net.
[b]Dace, redside shiner, sucker.
[c]Cutthroat trout, rainbow trout, mountain whitefish.
[d]Thirty cutthroat trout, 2 rainbow trout, 6 mountain whitefish.

Table 2. Catch and catch-per-unit effort (CPUE) by canal and fish group, all gear types combined, Teton River canals, 1995

Canal	Catch	CPUE fish/h
	Salmonids[a]	
Wilford	5	0.005
Teton Irrigation	29	0.073
Woodmansee-Johnson	1	0.001
Rexburg City	3	0.004
Total	38	
	Forage Fish[b]	
Wilford	280	0.264
Teton Irrigation	172	0.430
Woodmansee-Johnson	214	0.201
Rexburg City	155	0.200
Total	821	

[a]Cutthroat trout, rainbow trout, mountain whitefish.
[b]Dace, redside shiner, sucker.

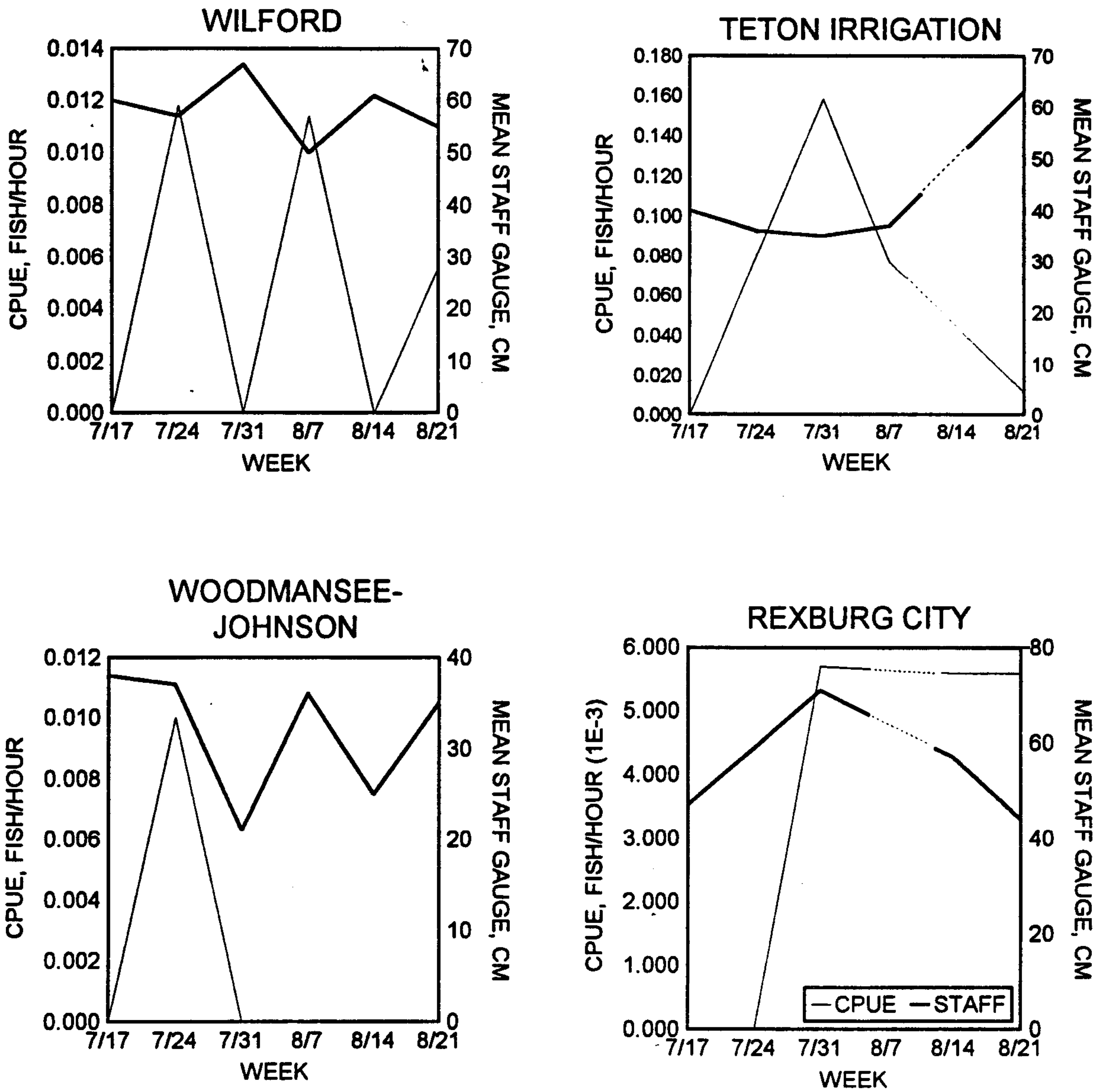

Figure 1. Catch-per-unit effort (CPUE) for salmonids relative to mean staff gauge height, Teton River canals, 1995. Dotted lines represent periods when traps were not fished.

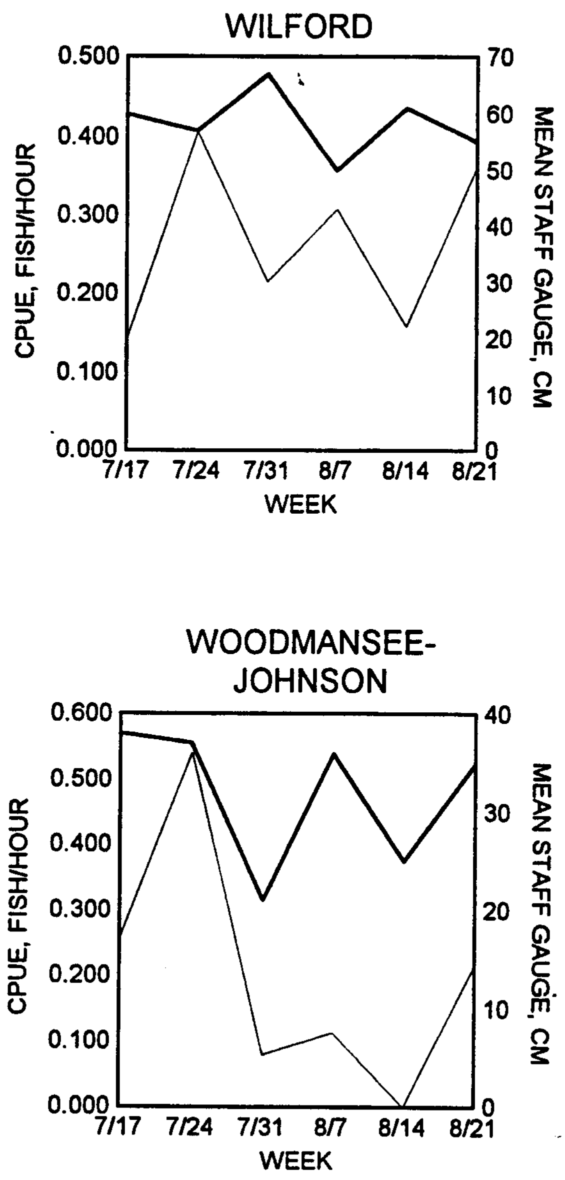

Figure 2. Catch-per-unit effort (CPUE) for forage fish relative to mean staff gauge height, Teton River canals, 1995. Dotted lines represent periods when traps were not fished.

Table 3. Total length (mm TL) of trout captured in Teton River canals, 1995.

Species	n	Length. mm TL Range	Mean	SD
Cutthroat trout	28	42-212	57	15
Rainbow trout	2	38-42	40	3

Although probably few in number, large fish were certainly present in the study canals. Trout larger than 150 mm were collected below the headgate in the Wilford Canal with electroshocking gear in November, and the presence of large trout has been documented in this canal in the past (Gamblin 1987). One trout larger than 200 mm was also caught in a hoop trap in the Rexburg City Canal. Low instream trout densities may have influenced canal losses, and hence, canal catch rates. In 1993, the estimated densities of age 1 and older trout in the North and South forks of the Teton River were only 60 and 30 fish/ha, respectively. Conversely, estimated densities of age 1 and older trout in the South Fork Snake River ranged from 169 to 239 fish/ha in 1995 (Bill Schrader, Idaho Department of Fish and Game, personal communication). Also, herbicide applications may have reduced catchable populations in two of the study canals.

The fyke net and screw trap used in the Teton Irrigation Canal had the best catch rates, but whether this was a function of trap effectiveness or higher fish densities in this canal is unclear. Regardless of the reason, these trap devices are restricted to use in canals with relatively high water velocities, which generally is not the rule in most canals. The hoop traps apparently fished poorly, but this may have been due to seasonal-behavioral effects or other factors. Nonetheless, these traps were difficult to handle, particularly the larger, two-throated configuration. A smaller version (0.6 m diameter x 1.3 m long, two throats) would be easier to use.

Trap efficiency evaluations were problematic due to low catch rates and small sample sizes. Ideally, three to five marked groups of sufficient size should be released per predetermined change in staff gauge height to estimate mean efficiency for a given flow level (Russ Keifer, Idaho Department of Fish and Game, personal communication). Adequate release samples could be collected with electrofishing equipment, or hatchery fish could be used. However, these approaches would be labor- and material-intensive if canal flows are variable. Indeed, flows in the study canals (as indicated by staff gauge heights) fluctuated widely throughout the evaluation period (Figures 1 and 2). An additional confounding factor could be herbicide-related mortality of release groups.

CONCLUSIONS

The results imply that either: 1) fewer fish are actually lost to canals than suspected; or, 2) capturing fish directly in canals with traps inadequately monitors salmonid losses. In view of the seasonal, behavioral, density-dependent, and other factors that may have influenced the low catch rates, the first conclusion is premature. However, capturing fish directly in irrigation canals with traps is difficult. Trap efficiency evaluation is probably the most troublesome problem. Widely fluctuating canal flows require frequent releases of marked fish groups, which could be difficult if catch rates are low. Herbicide-related mortalities of release groups may also introduce serious bias. The efficiency of the fyke traps and hoop nets could have been increased if wings were employed, but the perception that these devices impede canal flows precluded their use. With these restrictions, further sampling effort with traps in large canals is not warranted.

Gebhards (1959) stated trapping fish at screen bypasses is the only means of determining the actual movement of fish down irrigation diversions. Rather than trapping fish directly in canals, fish of various sizes could be marked and released upstream of screened canals and recaptured in bypass canal traps. Recaptured fish would estimate the proportion of a stream population lost to diversions, from which the effects of "exploitation" by canals could be modeled. In some canals where bypass hydraulics discourage egress back to the host stream, trap efficiencies would not need to be estimated. Further, this method would preclude estimation of stream population levels since the proportion lost will be determined by recaptures of marked fish in the bypass traps. However, the number of screened diversions in streams where resident stocks exist may be limited.

RECOMMENDATIONS

Concentrate efforts on releasing marked fish upstream of screened canals and estimating losses by the number recaptured in fish screen bypass traps..

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A P P E N D I C E S

Appendix A. Paired-T test comparison between one-throated (HT1) and two-throated (HT2) hoop net catch rates, Teton River canals, 1995.

		CPUE. Forage Fish and Salmonids. All Sizes		
Canal	Date	HT1	HT2	Di
WIL	7/17-7/21	0.0437	0.2404	-0.1967
	7/24-7/28	0.4118	0.4235	-0.0117
	7/31-8/04	0.2946	0.1360	0.1586
	8/07-8/11	0.3523	0.2849	0.0674
	8/14-8/18	0.0563	0.2599	-0.2036
	8/21-8/25	0.5556	0.1783	0.3773
W-J	7/17-7/21	0.0224	0.4930	-0.4706
	7/24-7/28	0	1.0940	-1.0940
	7/31-8/04	0.0455	0.1140	-0.0685
	8/07-8/11	0	0.2266	-0.2266
	8/14-8/18	0	0	0
	8/21-8/25	0.2111	0.2222	-0.0111
REX	7/24-7/28	0.2651	0	0.2651
	7/31-8/04	0.0230	0.8046	-0.7816
	8/14-8/18	0.0449	0.1014	-0.0565
	8/21-8/25	0.2000	0.3556	-0.1556

MEAN[D]	-0.150506	MEAN1	0.1579
VARSED]	0.1381961	MEAN2	0.3084
SD[D]	0.3717474		
SEED]	0.1524277		
N	16		

MINIMUM DETECTABLE DIFFERENCE FOR N=16, ALPHA =0.05, BETA =0.1, TWO-TAILED (ZAR 1984, P 111): 0.3227

POWER OF T-TEST FOR N=16, ALPHA=0.05, D=0.32, TWO-TAILED (ZAR 1984, PP 111-112):

TBETA(1),15	1.3410	
ALPHA	0.05	= PROBABILITY OF INCORRECTLY REJECTING A TRUE HO
BETA	0.0901	= PROBABILITY OF ACCEPTING A FALSE HO
POWER	0.9099	= PROBABILITY OF CORRECTLY REJECTING A FALSE HO

HO = MEAN[D] =0; HA: MEAN[D]0
(ZAR 1984, PP 150-153)

T	0.987
T0.05(2),15	2.131

ACCEPT HO

ANNUAL PERFORMANCE REPORT

State of: Idaho

Grant No.: F-73-R-18. Fishery Research

Project No.: 7

Title: Irrigation Diversion Fish Loss Reduction

Subproject No.: 2. Inventory of the Physical Characteristics of Canals in Magic Valley. Southeast. and Upper Snake regions,

Contract Period: April 1. 1995 to March 31. 1996

ABSTRACT

Fifty canals, ranging in decreed size from 5 cfs to 1,197 cfs, were surveyed in Magic Valley, Southeast, and Upper Snake regions in 1995. Most of these diversions were situated on river bends (86%), had their headgates located directly on the river (72%), and had low gradients (x = 0.8%, SD = 0.4). Diversion dams were associated with 84% of the canals, and 10% of the diversions completely dewatered the river channel. Only one diversion was screened. Comparisons between canal capacity and mean daily summer stream flow data suggested several of the canal complexes surveyed could theoretically capture high percentages of host stream flow. Based on past research and the physical characteristics of the surveyed canals, it is likely many irrigation canals in Idaho have a high potential to divert game fish.

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INTRODUCTION

The relationship between fish loss and the physical characteristics of irrigation diversions has long been known. Clothier (1953) saw diversity in the physical characteristics of irrigation diversions on the West Gallatin River, Montana and reported variation in fish loss between canals. Spindler (1955) found losses of legal-sized game fish were highest in canals that capture a high percentage of stream flow, and in those with headgates located on river bends. Finally, the abundance, distribution, and migration of fish back to host streams have been shown to be influenced by the amount of cover in a canal (Clothier 1954; Gebhards 1958 and 1959; Fleming et al. 1987; Thurow 1988).

An inventory of irrigation canals and their physical characteristics will help identify diversion systems that adversely impact resident salmonid populations. This report details observations made in summer 1995 of irrigation diversions in Magic Valley, Southeast, and Upper Snake regions.

OBJECTIVE

To identify diversion systems that adversely affect resident salmonid stocks.

Task

To inventory the physical characteristics of representative irrigation diversions in Magic Valley, Southeast, and Upper Snake regions.

METHODS

Major watersheds in Magic Valley, Southeast, and Upper Snake regions were identified and lists of decrees were obtained from Idaho Department of Water Resources (IDWR). These lists contained decrees for main canals and laterals, as well as pumps. A preliminary sample was randomly selected from these lists, and watermasters were contacted for information to help tailor the selections. Only main canals were considered in the inventory. Lateral canals and pumps were omitted. Generally, 30% to 80% of the main canals in a given stream or stream section were included in the inventory.

Canals were surveyed from June through September and data were largely collected according to the methods in Spindler (1955). Data were collected at comparable locations downstream of the headgates in each canal.

Water velocity was determined by the float method (Welch 1948). A 5 m section was established as close to each headgate as possible and a below-surface float was timed from the upper to lower end of the section. Three velocity readings were averaged. Width and average depth were measured along one transect as close as possible to the headgate in each canal.

Depths were measured at 0.3 m intervals. To account for edge effects, average depth was determined by totaling the readings and dividing by one more than the number of observations. Velocity and depth were not measured in some canals due to excessively swift currents (>0.8 m/s) and depths (>0.9 m).

Canal gradient was measured with a clinometer from the headgate to a point about 15 m downstream of the intake. Canal angle was measured at the headgate by sighting down the stream and canal and recording the difference. Canals that paralleled the stream from the headgate downstream about 45 m were assigned an angle of zero degrees. Information on decree flow volumes was obtained from IDWR. Mean daily summer (May through September) stream flow data for 1994 (Brennan et al. 1994) were included to provide a comparison between canal capacity and stream flow. Stream flow data from the nearest upstream gauge station were reported. Stream flow data for 1995 were unavailable at the time this report was prepared.

Headgate location and kind of manipulation were recorded. Headgates located directly on the river were given "river" designations, and those located down the canal were given "canal" locations. Kind of manipulation was recorded as vertically ("Vert") or horizontally ("Horz") dosing. Relation to the river was recorded as "Bend" if a canal was located on a river bend, or "Straight" if on a straight section. Diversion dams were recorded as being present ("Y") or absent ("N"). Canals that dewatered the stream were designated by "Y" and those that did not by "N."

The height of drop structures (e.g., parshall flumes, check dams, etc.) downstream of headgates was recorded by measuring the distance between their highest point and the canal bottom. If a drop structure was not present, "N" was entered.

RESULTS

Fifty canals, ranging in decree size from 5 cfs to 1,197 cfs, were surveyed in 1995 (Appendix A). Most of these diversions were situated on river bends (86%), had their headgates located directly on the river (72%), and had low gradients (x = 0.8%, SD = 0.4). Comparisons between canal capacity and mean daily summer stream flow data suggested several of the canal complexes surveyed could theoretically capture high percentages of host stream flow.

All of the canals had vertically closing headgates. In one diversion (Little Butte Canal, Blackfoot River), the headgate delivered water to the canal via a 0.09 m^2, 22 m long tunnel in the concrete headwall. In eight of the other canals, water was delivered through varying lengths of 1 m diameter culvert. Nearly a quarter of the canals (22%) had some type of drop structure (generally parshall flumes) in the vicinity of the headgate. Some of these may prevent migration back to host streams.

Diversion dams were associated with 84% of the canals. These were generally permanent constructions of boulder or cement, but a few were temporary gravel berms. Four of the dams (Last Chance Canal, Bear River; Farmer's Own Canal, Fall River; Conant Creek Canal, Conant Creek, Fall River tributary; Last Chance Canal, Henry's Fork) ranged in height from 3 m to 7 m and may be barriers to upstream migration. Five (10%) of the canals completely dewatered the river channel by manipulation of their diversion dams. One other canal (Riverton Canal, Blackfoot River) usually dewaters the river, although this was not the case at the time it was surveyed (June 23).

Water velocity was generally less than 1.0 m/s and ranged from 0.1 m/s to 4.2 m/s. Average water velocity was 0.6 m/s (SD = 0.3, n = 36) without the outlier. Average width and depth were 8.8 m (SD = 5.4, n = 50) and 0.47 m (SD = 0.18, n = 34), respectively. Velocity and depth were not measured in some canals due to excessively swift currents (>0.8 m/s) and depths (>0.9 m). Canal angles ranged from 0° to 212° and averaged 50°.

One canal (Farmer's Own Canal, Fall River) was screened with a rotary drum. Two others (Albert Moser and Cub River Irrigation, Cub River) were screened about 30 to 40 years ago.

DISCUSSION

Spindler (1955) evaluated the relationship between fish loss and the physical characteristics of canal intakes on the West Gallatin River. He found fish losses were proportional to the volume of flow captured by canals in relation to stream flow, and losses of legal-sized game fish were highest in canals located on the outside of river bends. Canals with diversion darns sustained higher losses than those without, partly because the former capture a greater percentage of stream flow. Linear regressions of fish loss against velocity, gradient, depth, or width were not significant. It was thought that these features influence fish loss in combination. Canal angle, headgate location, and kind of headgate operation were not significant.

Most of the canals surveyed in 1995 were associated with river bends and diversion dams. These features can influence the percentage of stream flow diverted by a canal and hence fish loss, but other factors may also come into play. For example, Gebhards (1959) found fish loss seemed to be a function of population density in the vicinity of canals. Thurow (1980 and 1981) suspected trout losses would be particularly significant during low-water years when a higher percentage of stream flow is diverted' by irrigation canals. Canal density, timing of water withdrawals, life histories of potentially impacted species, etc. are also factors that undoubtably influence losses. Some canals may not pose as large a risk if they return back to host streams, or if flows are maintained throughout the winter for livestock.

CONCLUSIONS

Based on Spindler's (1955) research and the physical characteristics of the canals surveyed in 1995, it is likely many irrigation canals in Idaho have a high potential to divert game fish. However, other factors undoubtably influence canal fish loss. If losses of resident salmonids to irrigation diversions are significant, then identification of canals that adversely impact fish will be essential in terms of maximizing the benefits of loss management. A group of canal characteristics and other factors likely to result in the highest losses of game fish include, but are not limited to:

1. Canal intakes located on the outside of river bends in association with diversion dams, i.e., canals that divert a high percentage of stream flow.

2. Close proximity of canals to fisheries, spawning grounds, and rearing areas.

3. Early water withdrawals (April) and late headgate closures (November).

4. High canal density.

5. Presence of highly migrant resident populations.

Although fish losses may be high in diversion systems with these properties, loss prevention may not be effective if instream habitat quality is too poor to support fish. For instance, chronic dewatering by diversions, damaged riparian zones, limited instream cover, etc. are factors that should be considered in any impact assessment.

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APPENDICES

Appendix A. Physical parameters of canals inventoried in Magic Valley, Southeast, and Upper Snake regions from June to September 1995.

Diversion	River Dewatered	Headgate Location/Kind	Diversion Dam	Drop Structure m	Relation to River	Velocity m/s	Decreed cfs	1994 Mean Daily Summer Stream Flow cfs•	Gradient %	Width m	Depth m	Canal Angle
					Magic Valley Region							
Big Wood River												
Hiawatha	N	River/Vert	Y	N	Bend	0.5	100	-	0.5	7.6	0.48	79
District	N	River/Vert	N	N	Bend	0.8	373	248	1.0	12.1	0.49	51
Glendale	Y	Canal/Vert	Y	0.9	Bend	0.5	65	248	1.0	5.2	0.35	60
Baseline Bypass	Y	River/Vert	Y	N	Bend	1.0	90	248	1.0	9.3	0.62	0
Bannon	N	River/Vert	Y	N	Bend	0.6	17	248	0.5	3.3	0.34	0
					Southeast Region							
Bear River												
Last Chance	N	River/Vert	Y	N	Bend	--	440	914	1.0	13.84	--	0
Bench 3	N	Canal/Vert	N	N	Bend	0.5	218	914	0.5	8.4	0.58	125
Gentile Valley	N	Canal/Vert	Y	1.05	Straight	0.9	48	914	1.0	4.7	0.68	0
Riverdale Irrigation	N	Canal/Vert	Y	N	Bend	0.5	13	831	0.5	5.2	0.61	0
West Cache	N	River/Vert	Y	N	Bend	0.8	191	831	0.5	11.0	0.89	60
Blackfoot River												
Eastern Idaho Water	N	River/Vert	Y	0.75	Bend	0.4	56	20	0.5	6.0	0.79	57
Little Butte	N	River/Vert	N	N	Bend	0.5	14	18	1.0	4.8	0.67	129
Riverton	N	River/Vert	Y	N	Bend	--	16	18	0.5	3.4	0.55	98
Central	N	River/Vert	Y	N	Bend	0.3	16	18	1.0	2.0	0.11	98
Stevens	N	River/Vert	Y	N	Bend	0.1	5	18	0.5	2.4	0.26	0
Cub River												
Albert Moser	N	River/Vert	Y	0.50	Bend	0.9	55	--	1.5	4.3	0.32	30
Middle Ditch	N	River/Vert	Y	0.40	Bend	0.8	60	--	1.5	3.8	0.27	145
Cub River Irrigation	N	River/Vert	Y	N	Bend	1.6	155	--	1.0	5.1	0.41	40

Appendix A. Continued.

Diversion	River	Headgate	Drop	Diversion Structure	Relation	Velocity	Decreed	1994 Mean Daily Summer Stream Flow cfs'	Gradient %	Width m	Depth m	Canal Angle
					Southeast Region							
Mink Creek												
U. Preston-Riverdale	N	RiverNert	Y	N	Bend	**0.5**	30	--	0.5	**7.5**	**0.38**	36
L. **Preston-Riverdale**	Y	River/Vert	Y	**0.65**	**Bend**	0.1	6	--	0.5	4.6	**0.19**	**25**
Twin Lakes	Y	River/Vert	Y	**1.00**	**Bend**	**0.4**	310	--	0.5	10.1	**0.40**	40
Portneuf River												
Dempsey-Topaz	N	Canal/Vert	Y	**0.55**	**Bend**	0.4	32	--	0.5	**5.1**	**0.45**	**85**
Lava Irrigation	N	River/Vert	N	**0.85**	**Bend**	0.3	23	--	1.0	**5.6**	0.46	212
Portneuf-Marsh Valley	N	Canal/Vert	N	N	Straight	**0.5**	164	**131**	1.0	**10.5**	0.81	**95**
McCammon	N	CanalNert	Y	**N**	**Bend**	**--**	**69**	**131**	1.5	5.0	--	40
Snake River. Shelly to Blackfoot												
Reservation	N	River/Vert	Y	N	Bend	--	**615**	**5,996**	**0.5**	14.9	--	40
Blackfoot	N	River/Vert	Y	N	Bend	--	467	**5,996**	1.0	16.9	--	45
Danskin	N	River/Vert	Y	N	Bend	--	**285**	**5,996**	0.5	10.6	--	**15**
People's	N	River/Vert	Y	N	Bend	--	624	**5,996**	0.5	**16.5**	**--**	50
Wearyrick	N	Canal/Vert	Y	**N**	**Bend**	0.6	**88**	**3,157**	0.5	7.6	0.52	**53**
					Upper Snake							
Fall River. Grassey Lake to Chester												
Fall River	N	River/Vert	Y	**N**	**Bend**	**--**	**465**	**679**	1.0	**18.5**	**--**	60
Enterprise	N	CanalNert	Y	N	Straight	0.7	**199**	**679**	0.5	**8.7**	0.62	0
Marysville	N	Canal/Vert	Y	N	Bend	--	322	601	**0.5**	25.0	--	0
Farmer's Own	N	Canal/Vert	Y	N	Bend	**0.5**	107	601	**0.5**	6.2	**0.50**	10
Conant Creek	**N**	RiverNert	Y	**N**	**Bend**	**0.8**	63	--	1.0	**3.8**	**0.19**	**50**

Appendix A. Continued.

Diversion	River Dewatered	**Headgate Location/Kind**	Diversion Dam	Drop Structure m	Relation to River	Velocity m/s	Decreed cfs	**1994** Mean **Daily** Summer Stream Flow	Gradient %	Width m	Depth m	Canal Angle
					Upper Snake Region							
Henrv's Fork. below Fall River to **above** North Fork Teton												
Last Chance	N	River/Vert	Y	N	**Bend**	0.8	225	1,798	2.0	4.1	0.40	0
Salem Union	N	RiverNert	Y	N	**Bend**	0.8	**315**	1,798	0.5	9.1	0.69	30
Farmer's Friend	N	RiverNert	Y	N	Straight	--	322	1,798	0.5	13.2	--	0
Independent	N	RiverNert	Y	N	Bend	--	435	1,798	1.0	8.7	--	27
Egin	N	RiverNert	Y	N	Straight	--	423	1,357	1.0	**9.0**	**--**	45
Teton River. South Leiah Creek to below St. Anthonv												
Canyon Creek	Y	RiverNert	Y	N	Bend	0.5	70	--	0.5	8.0	0.35	115
Wilford	N	River/Vert	Y	N	Bend	0.3	286	873	**0.5**	10.6	--	56
Teton Irrigation	N	River/Vert	Y	N	Bend	4.2[b]	128	873	1.0	8.2	--	35
Siddoway	N	River/Vert	Y	N	Bend	0.7	33	873	0.5	3.3	0.32	110
Woodmansee-Johnson	N	Canal/Vert	Y	**0.35**	Straight	0.2	60	380	**0.5**	5.0	0.48	33
Rexburg City	N	River/Vert	Y	N	Bend	0.3	54	380	**0.5**	5.1	0.31	78
Rexburg Irrigation	N	Canal/Vert	N	N	Bend	0.8	300	--	**0.5**	9.6	0.50	72
Snake River. Heise to Lorenzo												
Anderson	N	River/Vert	Y	N	Bend	0.6	1,197	11,240	0.5	17.4	--	0
Farmer's Friend	N	River/Vert	N	1.0	Bend	--	**495**	11,240	1.0	**14.9**	**--**	30
Snake River. Menan to Idaho Falls												
Great Western	N	Canal/Vert	N	N	Straight	--	1076	5,902	0.5	26.4	--	45

[a] Summer (May-September) stream flow data from Brennan et al. 1994. **Data** for 1995 were **unavailable at** the time **of report preparation.**
[b] Velocity measured with a Marsh-Birney meter.

JOB PERFORMANCE REPORT

State of: Idaho Grant No.: F-73-R-18. Fishery Research

Project No. Z Title: Irrigation Diversion Fish Loss Reduction

Subproject No.: 3. Synopsis of Information on Behavioral Barrier and Guidance Systems

Contract Period: April 1. 1995 to March 31. 1996

ABSTRACT

Behavioral barrier and guidance systems exploit the voluntary responses of fish to controlled stimuli. These systems are being considered as economic alternatives to fish screens for reducing the emigration of resident salmonids into irrigation diversions. This synopsis reviews the efficacy of behavioral systems that used hanging chain curtains, air bubble and water jet curtains, lights (incandescent, strobe, and mercury), and sonics. These systems can be effective under certain conditions. However, species- and lifestage-specificity, variable environmental conditions, engineering constraints, and other device limitations can affect their efficiency. Solar power requirements for the operation of these systems in remote locations also diminish their economic attractiveness, although efficient system components may offset costs.

Light and sonic barriers represent the most promising alternatives to fish screens among the behavioral systems reviewed, but each have limitations. For instance, light barriers are probably not effective during daylight hours and may be limited by their small area of influence. Sonic devices may only elicit an avoidance response from salmonids at short distances, which greatly limits their utility at large intakes. Although these limitations restrict the scope of their use, behavioral systems may be effective in small-scale applications. However, the potentially high cost of solar power is a limiting factor. Still, the probability of success of light and sonic behavioral barriers in small streams may be quite high. Streams characterized by small diversions with access to power, migrant populations, and nocturnal movement are likely candidates for implementation of behavior-modification systems.

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INTRODUCTION

The Idaho Department of Fish and Game (IDFG), with federal hydropower mitigation funding, currently maintains several irrigation diversion screen sites to protect migrating anadromous salmonids. Only a few diversions are equipped with screens for protection of resident fish. Although these screens are generally effective, older perforated-plate screens require frequent cleaning, while relatively easier to maintain rotary drum screens are expensive to install. Initial construction costs for rotary drum screens are about $3,000 to $4,000 per cfs (Mike Mitchell, Idaho Department of Fish and Game Engineering, personal communication) and though funding of this magnitude is typically available for anadromous fish stocks, it is uncommon for resident salmonid populations (Electrical Power Research Institute 1986). A proposed amendment to the Northwest Power Planning Council's Fish and Wildlife Program would provide funding for up to 40 resident fish screening projects per year in Idaho. Without outside funding of this nature, significant use of screens for resident salmonid protection is unlikely.

Behavioral barrier and guidance systems exploit the voluntary responses of fish to controlled stimuli. Exploitation of behavior for managing fish at water intakes and diversions has received considerable attention (Hocutt 1980; Electrical Power Research Institute 1986). Recent studies have shown behavioral barriers, given proper design and environmental conditions, may effectively prevent losses of warmwater and estuarine species to power facility water intakes (Haymes et al. 1984; Patrick et al. 1985; Empire State Electric Energy Research Corporation 1985 and 1986; Haymes and Patrick 1986; McIninch and Hocutt 1987; McKinley et al. 1988; Martin et al. 1993; Ross et al. 1993; Metropolitan Edison Company 1994). This information has renewed interest in the potential of behavioral barriers for protecting salmonids, although most research has focused on anadromous species in laboratory settings.

The prohibitive costs associated with the widespread use of rotary drum screens in irrigation diversions to protect resident salmonid stocks makes the *apparent* economy of behavioral barrier and guidance systems attractive. The question is whether such devices are effective, feasible, and more economic to install and operate. A summary of information on these devices will provide direction for future investigations.

OBJECTIVE

To determine whether behavioral barrier and guidance systems represent effective alternatives to fish screens.

Task

To provide a synopsis of the literature on behavioral barrier and guidance devices for protection of salmonids at irrigation diversion intakes.

METHODS

I conducted a comprehensive search of the literature and contacted biologists in other states for information on behavioral barrier and guidance systems as they pertain to salmonids. Of specific interest were devices and systems that use hanging chain curtains, air bubble and water jet curtains, lights (incandescent, strobe, and mercury), and sonics.

RESULTS

Hanging Chain Curtains

The biological principle behind hanging chain curtains is that fish see and avoid physical obstructions. Variables affecting performance include water velocity, turbidity, light/dark conditions, and debris load. Hanging chain curtains are inexpensive and can be easily retrofitted or combined with other types of behavioral barriers (e.g., strobe lights and/or DC current). Unfortunately, the effectiveness of hanging chains is variable and has been shown to be species- and/or lifestage-specific. Further, debris build-up can deflect the chains into a non-uniform pattern or disrupt the desired hydraulic flow distribution (Electric Power Research Institute 1986).

Most research with hanging chains has been directed at diverting downstream migrant salmonids with angled chain arrays. In laboratory studies using sockeye salmon *Oncorhynchus nerka* smolts, Brett et al. (1954) tested the effectiveness of a hanging chain guiding system in a divided trough. In one alley of the trough, a wall of safety chain hung at 5 cm to 8 cm intervals was positioned at a 45° angle to water flowing at 0.46 m/s. At night, an average of 71 % of the fish were deflected. However, yearling coho salmon O. *kisutch* were frequently not diverted.

In another study, Brett (1955) demonstrated a three-row array of safety chain vibrated at 140 rpm to 160 rpm increased the deflection of sockeye salmon migrants. The most effective configuration involved a guiding angle of 57° with 10 cm spacings. Still, this arrangement failed to deflect young coho salmon.

Related investigations by Brett and Alderdice (1958) on the Hooknose River, British Columbia studied the efficacy of charged (DC), traveling (20 cm/s to 30 cm/s) weighted cables spaced 5 cm apart for guiding young salmon. A piece of sheet metal painted white was also placed on the streambed below the path of the cable array to reflect incident light. Although chum O. *keta,* pink O. *gorbuscha* and coho salmon fry were not deflected, yearling sockeye and coho salmon were deflected at the 95% level and higher. Brett and Alderdice felt a DC charge was necessary for non-schooling species such as coho. Their recommendations included: deflect over a short distance along a natural migration corridor (i.e., inshore); deflect in areas not subject to strong turbulence, unnatural increases in subsurface flow, or velocity in excess of 0.6 m/s; maintain a barrier angle of 45° (t 5°) to flow direction; reduce extraneous visual clues; and create a moving curtain traveling in the direction of the bypass. They also suggested coating the upstream surface of the cables with luminescent paint.

Other researchers have reported poorer results. Fields et al. (1954a), working with sockeye, coho, and chinook salmon *O. tshwawytscha,* and steelhead trout O. *mykiss* smolts, tested a hanging chain blocking barrier under still water conditions in a divided trough. One alley was traversed (90° to flow) by chains spaced 10 cm apart, and the remaining lane was unobstructed. Only 56% of the fish were deflected at night.

Further laboratory studies by Fields et al. (1955a) looked at the response of hatchery steelhead trout, chinook and coho salmon fingerlings to hanging chain curtains in moving water (0.2 m/s to 0.5 m/s). Overall effectiveness using two barrier angles (90° blocking and 32º guiding) and chain spacings up to 10 cm was only 46%. Species-specificity was observed, with more steelhead than chinook, and more chinook than coho passing through the chain barrier. These researchers noted the smaller the angle and denser the chain barrier, the greater the number of fish that passed through it. However, this was attributed to light intensity in that the area downstream of the chain barrier was darker than the area upstream of the barrier. Fields and his colleagues concluded chain barriers were of no practical use in guiding young salmon under the conditions they tested.

Air Bubble and Water Jet Curtains

The intent of air bubble and water jet curtains is to create hydraulic conditions that fish avoid. The stimulus may be visual, tactile, or both depending on light conditions and the approach distance of the fish. Temperature, turbidity, light intensity, velocity, barrier angle, and debris can affect performance. As with hanging chain curtains, air bubble and water jet curtains are inexpensive and can be easily retrofitted or combined with other behavioral devices, but they also share the disadvantage of variable biological effectiveness. The diffuser orifices are subject to clogging from debris or rust as well (Electric Power Research Institute 1986).

Few studies have evaluated the response of salmonids to water jet and air bubble curtains, but results suggest these devices act as visual stimuli. Working in an irrigation canal on the Puntledge River, British Columbia, Brett and MacKinnon (1953) found an air bubble wall positioned at 40° to water flowing at 1 m/s did not effectively deflect chinook salmon fry at night. However, the most effective night of deflection occurred when they used bubbles plus a flashing (1 flash/s) sealed beam headlight. Hatchery rainbow trout fingerlings were not deflected under these conditions.

Bates and Vanderwalker (1964) tested vertical water jets in an experimental trough using hatchery-reared juvenile (6 cm to 10.5 cm) spring chinook salmon. The pipes were aligned at a 20° angle to flow leading to a 0.3 m diameter bypass. Mean efficiency was 75% at an approach velocity of 0.8 m/s. These researchers also tested air bubble curtains and reported up to 90% efficiency during daylight periods when velocity did not exceed 0.6 m/s. However, the air bubble curtain was ineffective at night and in turbid water, suggesting the curtain acted more as a visual than a tactile stimulus. Unsurprisingly, juvenile salmon were attracted to air bubble curtains under appropriate conditions of approach velocity, angle, and jet pressure.

Lights

Numerous studies have documented phototaxic responses in salmonids (Brett et al. 1954; Fields et al. 1954a; Fields et al. 1954b; Fields and Finger 1954a; Fields and Finger 1954b; MacCrimmon and Kwain 1966; Kwain and MacCrimmon 1969), with considerable research effort expended on using light to guide fish. Light has been investigated as both a repellent and attractant agent.

Incandescent Light

The principal intent of incandescent light is to repel fish through a negative phototaxic response. Variables affecting efficiency and performance include turbidity, velocity, light intensity, light adaptation, barrier length, and barrier angle. Incandescent lights are inexpensive and easily retrofitted, although species-specificity may compromise efficiency (Electric Power Research Institute 1986).

Preliminary research suggested, with some reservations, the potential of using incandescent light to guide fish. Fry (1950) noted moving lights (automotive bulbs) placed at the intake of a diversion on the San Joaquin River, California diverted fish to the main channel more effectively than electric shock warning devices. Brett and MacKinnon (1953) found that continuously illuminated and flashing (1 flash/s) sealed beam headlights had a positive deflecting effect with chinook salmon fry in an irrigation canal on the Puntledge River, British Columbia. A flashing narrow beam of light was most effective. However, hatchery rainbow trout *O. mykiss* fingerlings were not deflected. Brett et al. (1954) reported marked avoidance by sockeye salmon fingerlings to a lighted area in an experimental trough, but ambiguous results using a narrow beam of light.

The most promising research with incandescent light was conducted by Fields and his associates. Fields et al. (1954) investigated the efficiency of lights using various light intensities (0.9 to 87.0 foot-candles), barrier angles (25° to 75°), water depths (7.5 cm to 60 cm), and velocities (0.1 m/s to 1.0 m/s) in an experimental flume. They reported smaller barrier angles and higher light intensities were most effective for deflecting hatchery-reared yearling coho salmon. Velocity had a distinct effect, with deflection failure increasing with velocity. Depth had no effect because of water clarity.

Fields et al. (1955b), using hatchery-reared steelhead trout, chinook and coho salmon fingerlings, demonstrated differences between species in sensitivity to light. Each species was significantly deflected by a lighted 20° barrier, but based on avoidance response, steelhead were more sensitive to light stimuli.

Fields and Finger (1956) used hatchery-reared yearling coho salmon to test the effectiveness of constant and flashing incandescent light barriers (set 20° to water flowing at 0.6 m/s) and found there was no significant difference between the two. Since there was no difference, they suggested using more efficient mercury lights (which cannot be flashed). They also reported that the most effective condition involved illumination which did not reflect and diffuse to the dark side of the test flume.

Fields and Murray (1956) tested the effects of light adaptation by acclimating hatchery-reared yearling coho salmon to three light levels (dark, 8 foot-candles, and 100 foot-candles). They found that adaptation to a bright light (100 foot-candle) greatly reduced the guiding effectiveness of an 8 foot-candle barrier.

In field investigations conducted on Minter Creek, Washington, Fields et al. (1956) tested a 12 m long T-shaped barrier equipped with 25 watt (W) and 200 W lamps evenly spaced on the upstream and downstream sides of the structure. Light-proof curtains confined the light to a rectangle 0.3 m wide by 12 m long. The barrier could be pivoted to direct fish to the right or left bank at 35° to the flow. The creek was 8.5 m wide at the test site and water velocity underneath the light barrier ranged from 0 m/s to 0.6 m/s. Wild downstream migrant coho salmon, steelhead and cutthroat trout *0. dark/* were the species of concern; hatchery-reared coho salmon were also released to compare the response of wild and hatchery fish. Both hatchery-reared and wild coho salmon avoided the light barrier, and there was no significant difference in guiding efficiency for the respective groups. There was no significant difference between guiding efficiencies for the 25 W and 200 W lamps (about 50% mean efficiency for each light intensity), nor between shaded (downstream) and unshaded (upstream) illumination. However, there was a gradual reduction in effectiveness as the period of continuous illumination with the 25 W and 200 W bulbs was lengthened from 1 to 4 hours. When 7.5 W bulbs were used, a reduction in efficiency was not apparent and there was still a significant blocking effect. There was evidence fish moved through the barrier when the daylight and light barrier levels were equal. The authors thought lighted barriers would be most effective at velocities high enough to prevent downstream migrants from holding position. In deep, still waters, the authors suggested flashing lights or sequentially moving blocks of light would be required.

In the White River diversion canal, Washington, Fields et al. (1958) tested lighted barriers under fast, turbid water conditions. Canal width at the test site was 25.5 m. Velocity ranged from 1.2 m/s to 2.4 m/s with a mean of 1.8 m/s; visibility ranged from 7.5 cm to 1.8 m. Underwater lamps (200 W) and above water lamps (300 W) were strung along each bank of the canal. Wild downstream migrant steelhead trout, chinook and coho salmon were the species of concern. Statistically significant deflection (P = 0.01) of fish away from their preferred bank occurred when above water lamps (41 W to 300 W lamps spaced 1.5 m apart) were extended 64 m upstream from the collection site. There was no significant difference between guiding efficiencies obtained with above water and underwater lights. Repulsion with lights was significantly more effective in clear, high velocity water than in turbid water (79% versus 63% guiding efficiency), although statistically significant deflection was also obtained under turbid conditions. Interestingly, migrants given the opportunity to become light-adapted in velocities less than 0.2 m/s were attracted to low intensity light sources. Utilization of dim lights (25 W, 0.015 foot-candles) shining directly into the water, or of dim lights shining up into the sky from behind a barrier, effectively attracted fish in clear and turbid water.

Strobe Light

Strobe light is intended to repel fish by eliciting an avoidance response. Velocity, turbidity, light adaptation, barrier length, and flash duration all influence guiding efficiency. Strobe lights are relatively inexpensive, can be easily retrofitted, and have the potential for enhancing other fish protection systems (e.g., air bubble curtains). Although some results are encouraging, field evaluations on the effectiveness of strobe light for repelling salmonids are limited and equivocal. Design and operational problems have also been encountered (Electric Power Research Institute 1986).

In laboratory studies, rainbow trout (15 cm to 70 cm), coho (12 cm to 90 cm), and Atlantic salmon *Sa/mo* sear *(14* cm to 18 cm), exhibited strong avoidance to strobe light at current velocities up to 0.6 m/s (Canadian Electrical Association 1985). However, at velocities of 1.0 m/s, strobe light was' ineffective since most species were swept down the test channel. Chinook salmon (4 cm to 6 cm) showed slight avoidance at a velocity of 0.1 m/s, but displayed no aversion under static conditions. In field tests conducted at the Lennox Generating Station forebay, Lake Ontario, rainbow trout (15 cm to 23 cm) and coho salmon (7 cm to 10 cm) were markedly repelled by strobe lights at night. Effectiveness ranged from 32% to 90% for rainbow trout and 20% to 93% for coho salmon.

Riverine tests at the Seton Generating Station, Seton Creek, British Columbia demonstrated strobe light could evoke a moderate avoidance response (56% guiding efficiency) from migrating sockeye salmon smolts (Canadian Electrical Association 1987). Guiding efficiency was limited by high current velocities, which approached 1 m/s near the device. Guiding efficiency also appeared to be related to the area of influence of the device (probably less than 5 m since light levels beyond this distance were minimal).

Puckett and Anderson (1988) tested strobe light in•a covered raceway under static conditions. They used young-of-the-year steelhead trout, coho, chinook, and Atlantic salmon. All species avoided strobe light at night. The coho and chinook salmon also avoided strobe light during the day, but the authors felt this was due to experimental conditions rather than a true open-water response.

Anderson et al. (1988) studied the problems contributing to the ineffectiveness of a prototype submersible traveling screen at the Rocky Reach Dam, Columbia River, Washington. They tested the feasibility of using strobe light to enhance screen performance. In laboratory experiments under static conditions, chinook salmon, rainbow, and steelhead trout fingerlings exhibited escape, attack, stun, and attraction responses to strobe light. An escape response was elicited when the light stimulus was of intermediate strength (0.1 to 5 micro Einsteins (pE)/m^2/s) and fish perceived an escape route. • Escape speed was probably dependent on the level of light adaptation. When fish were adapted to high light levels, they exhibited a weaker response, with the lowest response at 0700 hours and the highest at 2300 hours. The fish were stunned when light intensity levels exceeded 5 pE/m^2/s and flash rates were greater than 500 per minute. At low light intensities, such as the appearance of a strobe at a distance, fish were attracted to and would hover at the fringe of the light. The authors reported the fish consistently responded to and, for the most part, tended to move away from the strobe light.

Further laboratory experiments were conducted by Anderson et al. (1988) to determine if fish could be forced through vertical bars, which simulated a trashrack, by strobe light. Without strobe light, only 28% of rainbow trout tested could be forced through the vertical bar barrier. With a strobe light behind the fish, 75% passed through the barrier. However, strobe light was ineffective at forcing subyearling chinook salmon through a trashrack located in front of the screen at the Rocky Reach Dam site. The authors hypothesized the submersible screen generated sound stimuli that inhibited thrash rack passage.

In field tests at Weldon Dam, Maine, Atlantic salmon smolts exhibited an avoidance response to strobe light (Great Northern Paper 1995). Strobe light was used to create a barrier wall in two of four turbine forebays (1 and 2). In forebays 3 and 4, strobe lights were placed at depth to deter sounding and direct fish upwards to a fish bypass system. There was a 54% reduction in the passage of radio-tagged fish through intakes 1 and 2 after strobe lights were installed. In total, 85% of radio-tagged smolts were redirected to intakes 3 and 4. However, these fished were reluctant to enter the fish bypass. Possible reasons included light contrasts, stray lighting from the strobe lights, and hydraulic changes at the bypass inlet.

Mercury Light

Mercury light is intended to attract fish, either away from hazards or toward a safe area of passage. Data are insufficient for most variables that potentially affect performance, although limited testing with warmwater species (Haymes et al. 1984) suggests ambient light levels and turbidity influence efficiency. Mercury lights are relatively inexpensive, can be easily retrofitted, and may improve existing fish protection systems. However, the effectiveness of mercury light may be species- and/or lifestage-specific, but again, data are insufficient to draw conclusions. Engineering and design work are needed to adapt mercury lights for underwater use (Electric Power Research Institute 1986).

Laboratory evaluations conducted at night with coho salmon (12 cm to 90 cm), rainbow trout (15 cm to 23 cm), and lake whitefish *Coregonus clupeiformes* (32 cm to 43 cm) were equivocal (Canadian Electrical Association 1985). Whitefish displayed a slight avoidance response, while coho salmon and rainbow trout exhibited no attraction whatsoever. In field evaluations at the Lennox Generating Station, Lake Ontario, coho salmon (7 cm to 10 cm) were not attracted to mercury light.

In other laboratory tests under static conditions, responses to mercury light by under yearling coho, Chinook, and Atlantic salmon were variable (Puckett and Anderson 1988a). However, steelhead trout fry were strongly attracted. The authors suspected sensitivity to mercury light was age-dependent.

<u>Sonics</u>

The use of sonics to guide fish is dependent on their acoustic receptive capabilities. Tavolga (1980) noted non-ostriophysines (fish without a Weberian apparatus, e.g., salmonids) are virtually deaf to frequencies above 2 kHz, whereas ostariophysines can generally detect frequencies of 5 kHz or more. Further, the ability of non-ostariophysines to differentiate between sounds of different intensities is limited (30 dB range) compared to ostariophysines (3 dB to 6 dB range).

The intent of using underwater sonics is to create frequencies and amplitudes that repel or attract fish. Data are insufficient for most variables that affect performance, but area of influence and sound pressure wave intensity seem to be important factors. Sonic devices are relatively inexpensive and can be easily retrofitted, but their biological effectiveness is variable.

Species- and/or Restage-specificity, habituation, and limited range of effect are potential disadvantages (Electric Power Research Institute 1986).

Results from early sonic studies were not promising. Moore and Newman (1956) tested the effects of electromagnetic and piezoelectric transducers on yearling coho salmon in laboratory and open water experiments. In the laboratory studies, continuous and various pulse patterns at frequencies between 10 Hz and 8,000 Hz elicited an initial "start" reaction, but none of the frequencies tested demonstrated an attracting or repelling force. The open water tests evaluated frequencies between 5 Hz and 20,000 Hz, with the same results. The "start" reaction was most pronounced at low frequencies. The authors reported the fish seemed to habituate to sounds instantaneously.

Burner and Moore (1962) tested a water hammer, underwater turbine, piezoelectric transducer, and electromagnetic transducer on rainbow trout (10 cm to 30 cm) and brown trout *Salim trutta* (4 cm) in laboratory experiments. Frequencies between 67 Hz and 10,000 Hz (generated by the water hammer, underwater turbine, and electromagnetic transducer) yielded significant differences in fish distribution between sound and control tests, but there was no definitive attracting or repelling effects. Frequencies produced by the piezoelectric transducer (12,000 Hz to 70,000 Hz) did not provoke any response.

Later studies produced largely equivocal results. Vanderwalker (1967), working with downstream migrant steelhead trout in an irrigation canal near Umatilla, Oregon, tested a steel plate array agitated with air driven vibrators operating at 270 Hz. This device diverted 77% of the migrants with the vibrators on versus 33% when they were off. However, in tests with a similar device (the "fishdrone", a device that uses sonic vibrations to excite a metallic structure) at the Lennox Generating Station (Empire State Electric Energy Research Corporation 1986; McKinley et al. 1988), rainbow trout did not respond to any of the frequencies evaluated (27, 64, 99, and 153 Hz).

Preliminary laboratory investigations to test the effectiveness of a pneumatic "popper" indicated rainbow trout (15 cm to 23 cm), coho salmon (12 cm to 18 cm) and Atlantic salmon (14 cm to 18 cm) all avoided the device (Canadian Electrical Association 1985). However, in further tests at the Lennox Generating Station, coho salmon (7 cm to 10 cm) did not show any avoidance response. In fact, there were more fish observed in the experimental area than in the control area, suggesting an attraction response. Conversely, a pneumatic popper diverted 66% of sockeye salmon smolts at the Seton Generating Station (Canadian Electrical Association 1987).

Despite these findings, some research has shown promise. Riverine tests at the Seton Generating Station with the "Fishpulser" (U.S. Patent 4,646,276), a spring-mass impact device (Empire State Electric Energy Research Corporation 1986), indicated it effectively (75% guiding efficiency) deflected sockeye salmon smolts (Canadian Electrical Association 1987; McKinley et al. 1988). The device operated at an impact rate of approximately 20 times per minute and had a fundamental frequency of 52 Hz. Current velocities in the forebay approached 1 m/s. The effectiveness of this device was attributed to its relatively high sound pressure levels and directional area of influence. The need to better define the area of influence of this device was identified, but in previous tests with alewife *A/osa pseudoharengus,* fish were deflected at distances up to 5 m away from the test unit (Empire State Electric Energy Research Corporation 1986). The latest upgraded version of this device weighs approximately 250 kg and is operated by a Y2 HP, 120 V AC, 60 Hz motor. Future development of smaller versions of the Fishpulser may be forthcoming due to inquiries for remote applications (Jerry Forest, Ontario Hydro Technologies, personal communication).

Loeffelman et al. (1991) analyzed the sounds of immigrant/emigrant chinook salmon and steelhead trout, and then synthesized a signal with a waveform generator. They enhanced it with an octave equalizer when necessary, and radiated it with a roving coil projector (underwater speaker). In tests conducted at the Berrien Springs Hydroelectric Project, Saint Joseph River, Missouri, 72% of immigrant steelhead trout were diverted using a two-frequency crescendo signal. A three-frequency crescendo signal developed from chinook salmon sounds effectively diverted immigrant chinook salmon, but a signal synthesized from steelhead trout did not. At the Buchanan Hydro Station, Saint Joseph River, Missouri, 81 % and 94% of outmigrant chinook salmon and steelhead trout, respectively, were diverted. The authors concluded sound could modify fish movement in spite of environmental stimuli (e.g., water temperature, daylight), and signals could be rapidly customized for fish species, life stages, and project site conditions.

Knudsen et al. (1992) tested the effects of 10 Hz and 150 Hz frequencies on wild and hatchery juvenile Atlantic salmon (10 g to 100 g) in an artificial pool. The 10 Hz component was produced by a 1.2 m long aluminum tube fitted with a 19 cm piston driven by an eccentric coupling to an electric motor running at 600 rpm. The 150 Hz component was supplied by an underwater loudspeaker. When exposed to the 10 Hz component, the fish generally exhibited an avoidance response within areas of the pool where the sound intensity was 10 dB to 15 dB above the threshold for spontaneous awareness reactions (approximately 50 dB at 10 Hz). The 150 Hz component did not elicit an avoidance response, even when the sound intensity was greater than 30 dB above the awareness reaction threshold (approximately 90 dB at 150 Hz). Habituation required several hours in the pool experiments, which suggested it may not be a serious problem in situations where fish are only briefly exposed to sound deterrents.

A facsimile of the piston device used in the experiments conducted by Knudsen et al. (1992) was tested on Pacific salmon in Oregon (Bruce Schmidt, Oregon Department of Fish and Wildlife, personal communication). Pacific salmon were shown to be as sensitive to the 10 Hz frequency as Atlantic salmon, but the range of effect was limited (about 2 m). Field tests in a riverine environment were inconclusive due to high flows, and mechanical problems were encountered with the piston mechanism.

DISCUSSION

Although the devices themselves are relatively inexpensive and moderately effective in some situations, there seems to be no single behavioral barrier or guidance system that is universally applicable. Problems stemming from species- and/or lifestage-specificity, variable environmental conditions, engineering constraints, and other device limitations require site-by-site evaluation. Laboratory experiments may answer questions about specificity and the effects of environmental variability (e.g., changing current velocity, turbidity, and water temperature), but on-site assessment would be needed to determine effective barrier type, size, and placement.

Light and sonic barriers represent the most promising alternatives to fish screens among the behavioral systems reviewed, but each have limitations. For instance, light barriers are probably not effective during daylight hours (Fields and Murray 1956; Fields et al. 1956; Anderson et al. 1988; Puckett and Anderson 1988) and may be limited by their small area of influence (Fields et al. 1958; Canadian Electrical Association 1987). Sonic devices may only elicit an avoidance response from salmonids at short distances, which greatly limits their utility at large intakes (Bonneville Power Authority 1994). Although these limitations restrict the scope of their use, behavioral systems may be effective in small-scale applications.

Light and sonic devices obviously require power to operate. Since many irrigation diversions are located in remote areas, solar power is the logical choice. Unfortunately, solar power is not cheap, although efficient equipment can reduce costs. Start-up costs per watt-hour (Wh) for solar panels, batteries, and charge controllers are around $1.42 to $1.57 for sunny climates, and $1.97 to $2.68 for predominately cloudy environments (Steve Willey, Backwood Solar Electric Systems, personal communication). For nightly 9-hour usage during a typical irrigation season (May through October), this translates into a maximum cost of about $106 to power one 7.5 W incandescent bulb in a sunny climate, and $181 under cloudy conditions. The price tag jumps to $4,739 (sunny) or $7,236 (cloudy) to power one 300 W bulb. However, florescent lights are more efficient. A 25 W compact florescent will give light equal to a 100 W incandescent, but use just one-quarter the power. Maximum power consumption of the Flash Technology PC 901 power converter, sufficient to operate four strobe flashheads in the AquaFlash AGL 4100 behavioral barrier system, is 2400 W (Larry Montouri, Flash Technology, personal communication). Assuming 70% DC to AC inverter efficiency, maximum costs range from $48,452 (sunny) to $82,707 (cloudy). There may be more efficient alternatives. For instance, the strobe lights used on aircraft and school buses use 12 V DC, do not require an inverter, and have low power draw. Finally, the maximum cost to power the 1/2 HP (373 W output) motor needed to operate one Fishpulser, assuming 65% motor and 70% inverter efficiencies, ranges from $11,587 (sunny) to $19,778 (cloudy). However, a timer powered solenoid impact rather than a continuous motor would save power, particularly since an inverter is not required (Steve Willey, Backwood Solar Electric Systems, personal communication).

Light and sonic barrier systems may have small-scale applications, but solar power costs certainly restrict their utility. Consider a canal with a 60 cfs capacity and 6 m wide intake. Average stream depth in the vicinity of this canal is 1 m, average width is 18 m, and mean velocity is 2 m/s. Assuming a mean swimming speed of 0.4 m/s for juvenile fish at spring water temperatures, a fish would need to begin swimming laterally about 18 m upstream of the intake to avoid it. This would theoretically require a 25 m long guiding barrier. Next, consider the use of strobe light or sonic devices. The cost of a Flash Technology AGL 4100 strobe light system for a 25 m barrier, which includes six power converters equipped with four flasheads each, is about $60,000 (Larry Montouri, Flash Technology, personal communication). Solar power start-up costs in a sunny climate for six units would be around $290,700; in a cloudy climate, the cost soars to about $496,200. Disregarding engineering and installation costs, this translates into $5,845 to $9,270 per cfs for equipment alone. This compares with $3,000 to $4,000 per cfs for rotary drum screens. On a somewhat more economic note, the Fishpulser sonic device costs about $20,000 per unit (Bob Elliott, FMC of Canada Limited, Material Handling Operation, personal communication). Assuming an area of influence of about 5 m for each device, a minimum of 5 units ($100,000) would be needed to create a 25 m barrier. Solar power start-up costs in a sunny climate for 5 units would be about $58,000; in a cloudy climate, the cost would be around $99,000. This translates into $2,600 to $3,300 per cfs for equipment alone. Still, the probability of success of light and sonic behavioral barriers in small streams may be quite high. If solar power was not a concern, equipment costs for the strobe light and sonic barrier systems for the above scenario would run about $1,000 and $1,700 per cfs, respectively. Streams characterized by small diversions with *access to power,* migrant populations, and nocturnal movement are likely candidates for implementation of behavior-modification systems.

Judging from the literature and personal contacts, the use of behavioral systems to protect salmonids at irrigation diversion intakes seems to be non-existent. However, there is continuing research and development of strobe light and sonic devices. For example, a study is currently being designed by the Oregon Cooperative Fish Research Unit to test strobe light in an Oregon diversion (Ron Brown, Flash Technology, personal communication). Future development of smaller versions of the Fishpulser sonic device may be forthcoming due to inquiries for remote applications (Jerry Forest, Ontario Hydro Technologies, personal communication). These and other efforts should be monitored to see if such devices warrant consideration.

RECOMMENDATIONS

1. Monitor current research on light and sonic behavioral barriers (e.g., the Oregon Cooperative Fish Unit strobe light study) to determine if such devices warrant further consideration.

2. If losses of resident salmonids are significant and results from current research are promising, test light and/or sonic behavioral barriers in small streams that have canals with a power supply.

3. If the behavioral barrier tests are successful, consider solar power, evaluate cost-benefit of loss management, and make recommendations.

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